

# Neutrino interactions theory discussion

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Intermediate Neutrino Program

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# $\nu$ interactions

- with itself, Higgs and BSM particles (talks of P. Huber, B. Kayser, L. Everett, I. Mocioiu)
  - with production target  $\sim\checkmark$  (measure flux w/detector)
  - with matter: solar, SN, earth (talk of A. Friedland)
  - with detector:
    - electrons  $\checkmark$
    - protons
    - nuclei
      - low-E (nuclear structure, shell model)
      - high-E
        - low/moderate- $Q^2$  (QE, resonance, nuclear IS, FS)
        - high- $Q^2$  (DIS)  $\sim\checkmark$
- focus some attention here
- (talks of J. Carlson, W. Donnelly, S. Dytman)

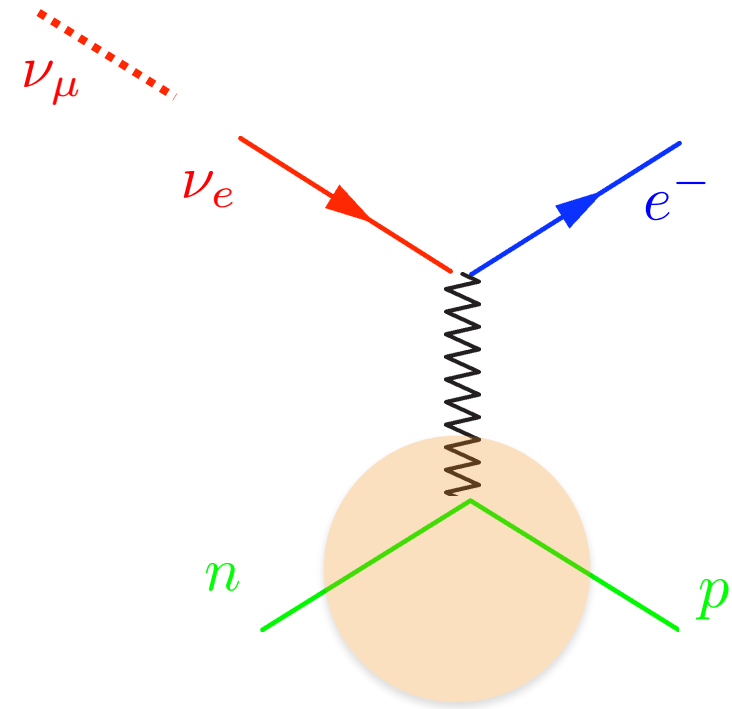
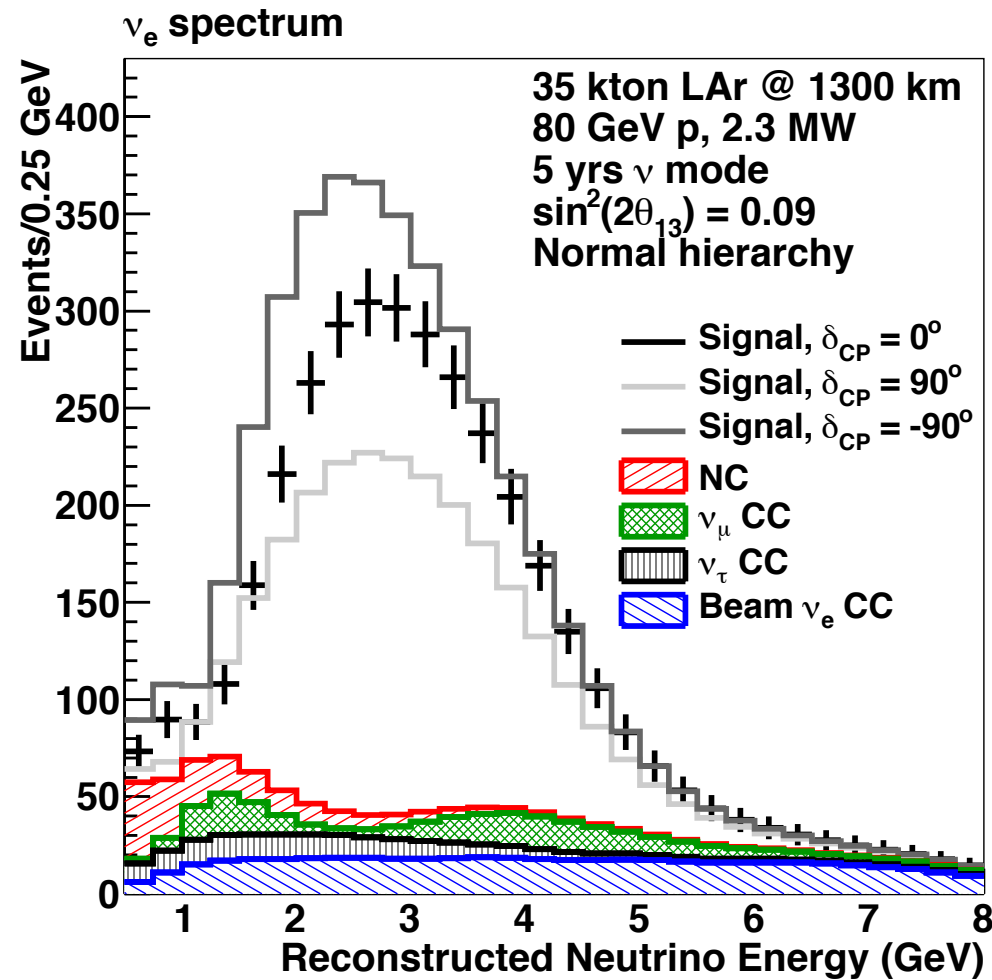
Have established a new physics scale

$$\frac{1}{\Lambda} H H E E \qquad \Lambda \sim \frac{v_{\text{weak}}^2}{m_\nu} \sim 10^{14} \text{ GeV}$$

Neutrino physics is living the dream.

Exploring the new physics at this scale takes us outside of the HEP comfort zone. That's ok.

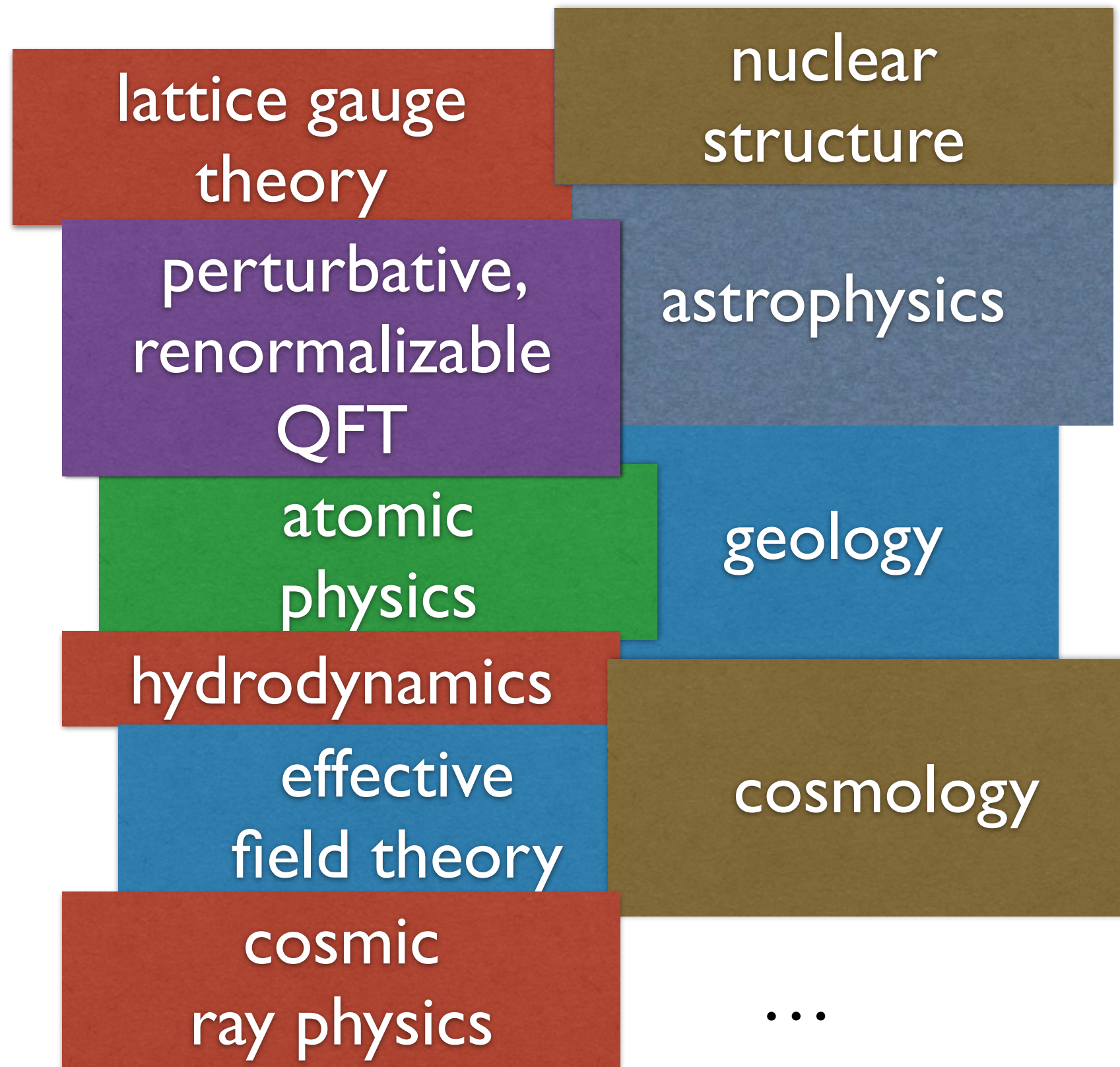
*- where are the HEP/astro/NP dividing lines? Are they useful and how do we deal with them?*



Many components of the problem

- neutrino parameters
- experimental systematics
- neutrino-nucleus interaction

- *neutrino oscillations*
- *supernova constraints*
- *nucleon decay*
- *WIMP searches*
- *$\mu \rightarrow e$  conversion*
- *EDMs*
- *Onub*
- ...



at a critical and exciting time, important that HEP not define itself out of existence at “intensity frontier”

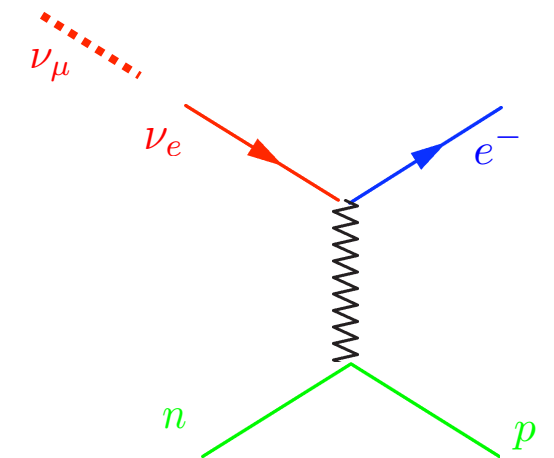
## a cautionary tale: proton radius puzzle

in case you haven't heard: extreme confusion in a problem intimately related to neutrino scattering

most mundane resolution involves 5 sigma shift of fundamental Rydberg constant, and “revisiting” decades of electron scattering (and hydrogen) data

impacts important signal cross section for LBNF (CCQE on bound neutron)

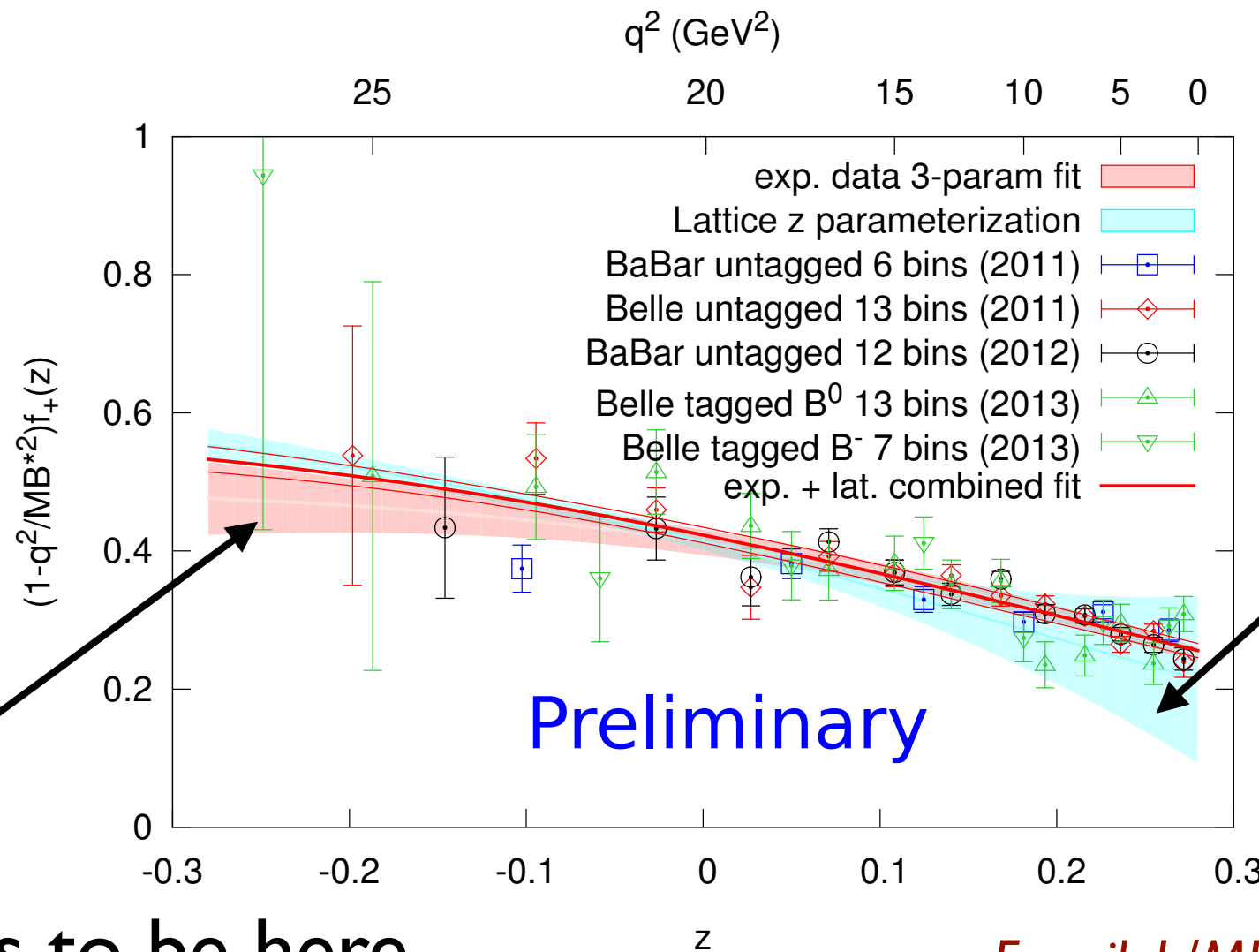
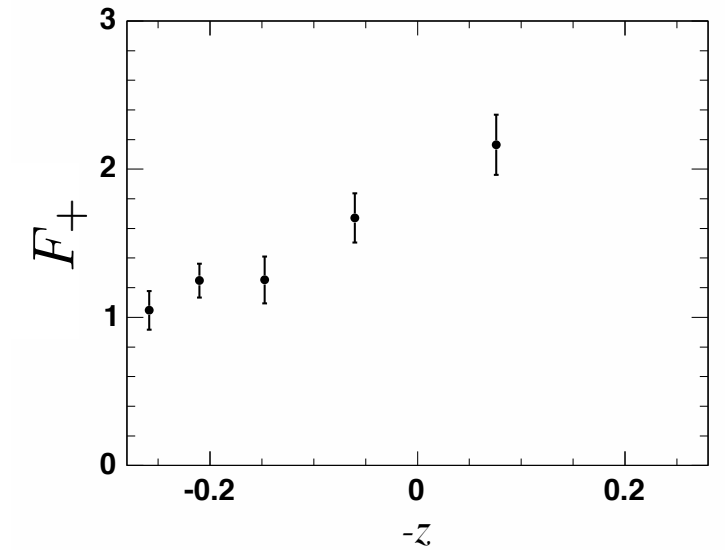
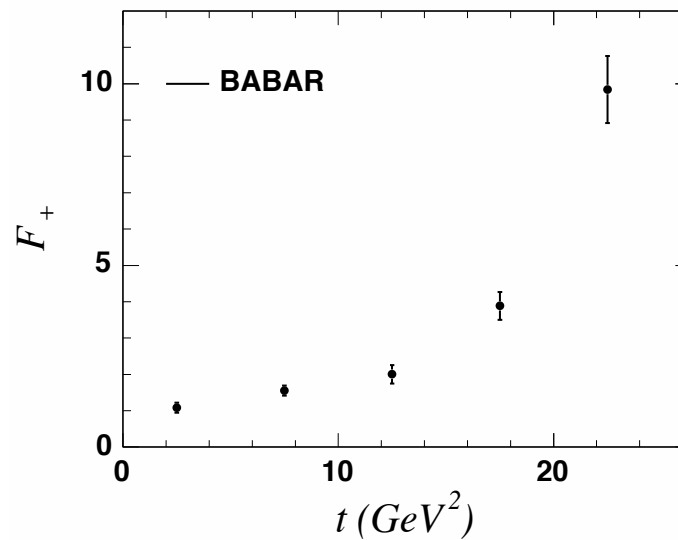
- modified vector form factors
- same issues of shape assumptions for axial FA



typically quoted precision for neutrino observables *small* compared to discrepancies and realistic uncertainties in electron-proton scattering (without flux, nuclear issues)

!!!!!!

# QCD, analyticity, lattice: (meson sector and precision CKM)



experiment wants  
to be here

lattice wants to be here

*Fermilab/MILC @ CKM 2014*

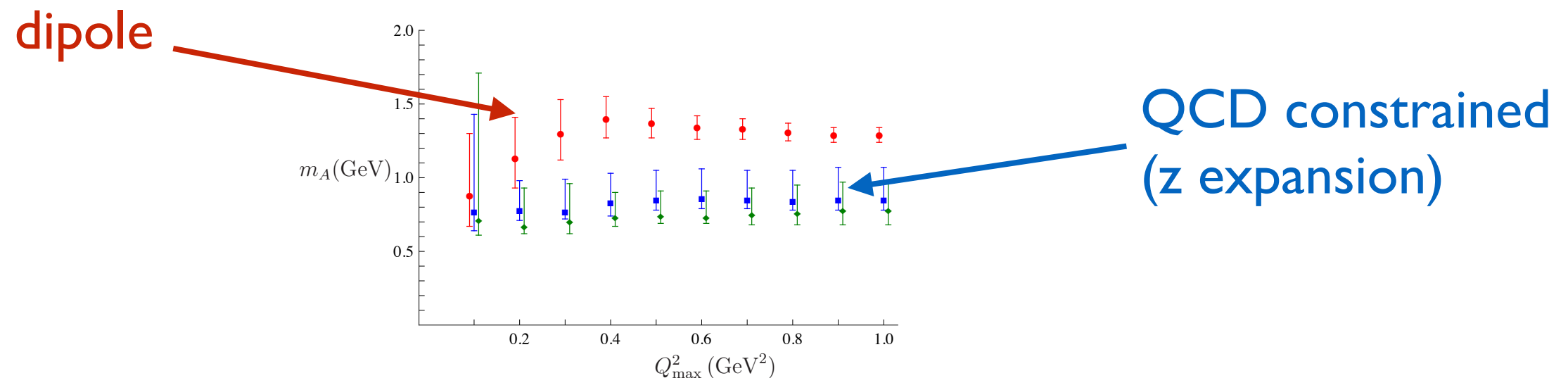


# QCD, analyticity, lattice: (baryon sector and precision neutrino studies)

next frontier of lattice QCD: precision baryon matrix elements (*neutrinos, dark matter, nucleon decay...*)

cf. 2014 USQCD Lattice Meets Experiment:

<https://indico.fnal.gov/conferenceTimeTable.py?confId=7873#all>



z expansion implemented in GENIE (A. Meyer)

uncertainties at both nucleon and nuclear level (~theorem: these are comparable in size. ~proof: constrained by same data)



## For discussion:

- where can HEP theory (people and methods) have most impact?
- where is the dividing line between HEP and other fields (NP, astro, ...)?
- what is the measure on interesting and answerable questions in Neutrino Theory - is it perceived to be small? Are there other barriers to participation?
- given infinitely precise nucleon-level amplitudes, what is the uncertainty from nuclear modeling?
- whose job is it to model nuclear effects?
- whose job is it to develop generators?